Patient Assessment Assistant Using Augmented Reality

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Abstract. Facial symmetry and averageness are key components in quantifying the perception of beauty. In this study, a prototype Augmented Reality (AR) tool is developed on Android OS, to assist plastic surgeons and patients in objectively assessing facial symmetry when planning reconstructive surgical procedures. Specifically, the tool overlays 4 types of measurements and guidelines over a live video stream to provide the users with useful information interactively. The measurements are computed from the tracked facial landmarks at run-time.

Keywords: Facial Symmetry, Facial Analysis, Augmented Reality, Android, Mobile Apps

1 Introduction

The human face is central to many aspects of social interaction. It forms the basis from which humans are able to process, recognize and draw information from one another. Even from infancy, humans are able to demonstrate a preference for faces perceived as attractive [Lit14]. Indeed, there have been several studies suggesting that individuals deemed as being attractive are more likely to achieve prestigious occupations, to have better prospects for personal fulfilment and to benefit from additional social advantages in their everyday lives [HLKJR+00,EAML91]. These observations have subsequently garnered the attention of researchers, in seeking to determine if attractiveness can be considered objective or subjective. It has been suggested through studies, both in the fields of psychology and medical science, that facial attractiveness can indeed be quantified [GT94].

Humans have evolved in such a way that they are able to perceive subtle deviations in what would be considered normal facial structure. Facial symmetry and averageness have consequently been identified as key components in this perception and several attempts to produce metrics for these elements have

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been proposed [Jef04,PBPV$^+$99,RPGS98]. The development of these attractiveness metrics has led to the development of several tools that can theoretically determine facial attractiveness based upon the proposed empirical data.

Recently, automated machine learning methods of assessing facial attractiveness using the beauty metrics have been proposed [SBHJ10,LLCC18,CLH$^+$14,HNC$^+$17]. These proposed frameworks focus on developing systems which automatically assess facial attractiveness based upon the facial proportions and specified landmarks typically associated with facial beauty. It is thought that automated technology capable of the quantifiable analysis and measurement of facial attractiveness could have many applications including entertainment, virtual media, cosmetics and plastic surgery [HNC$^+$17].

Given that facial symmetry has the potential to contribute greatly to the perception of facial attractiveness, the impact of facial asymmetry can lead to significant emotional and psychological distress [MBB$^+$13]. The UK Equality Act 2010 [Leg10] states that a severe facial disfigurement should be treated as a disability. In these cases, reconstructive plastic surgery is often considered necessary. In undertaking surgery to resolve facial asymmetry, surgeons will often manually determine the differences between the two sides of the face, simply by examining the patient subjectively. Working in close collaboration with the patient, surgeons tend to use the contralateral normal side as a guide rather than using the well-studied metrics discussed above. Whilst the implementation of technology has not been widely acknowledged in this area, it has been established there is certainly the potential for it to be very helpful.

Recent studies [MWM13,PIMG15,WHB$^+$16,NLK$^+$06] suggest that the implementation of computer-based assessment systems can provide an aid to surgeons in preparing, measuring and analysing facial reconstruction procedures. These studies typically demonstrate methodologies for the objective and quantifiable measurement of facial imperfections and provide a means of tracking treatment outcomes. These approaches utilise still images for comparison, which are generated either from photographs or 3D scans of the patient. These images are then analysed and overlaid with relevant information pertinent to the surgical processes such as predefined landmarks or volumetric comparisons. Whilst encouraging results using computer vision and computer-based assessment are evident from the literature, it is worth considering that the financial costs of implementing full clinical 3D systems, such as 3dMD [vLMP$^+$10], can be significant. Additionally, each of the related works considered deals only with still images, potentially neglecting vital information about the transitions between facial expressions.

To this end, we propose an AR-based prototype for objective assessment of facial deformation. Specifically, we have developed a smartphone application (with Android OS) which captures a 2D colour video stream of the patient, extracts important facial features such as facial landmarks and analyses the data in real-time. The results are then overlaid directly on the live video stream in order to assist both the surgeon and patient in determining the most appropriate surgical options interactively. The on-screen visual feedback provided by the overlaid visualisations are based upon several of the quantifiable metrics and guidelines discussed, allowing for objective and fully informed decisions to be made. The proposed assessment method is quick, cost-effective, non-invasive and avoids ionising radiation.

2 Related Work

The metrics incorporated into our prototype system are primarily based around the perceived notion that facial symmetry is a desirable trait. Based upon the literature there is also evidence to suggest that the golden ratio may contribute to the overall aesthetic of facial construction. The implementation of metrics such as these are a commonly found approach in many related works. In a recent study, Gunes and Piccardi [GP06] attempted to evaluate human facial attractiveness using an automated classifier. A decision tree extracted features from the images based upon the golden ratio and, through supervised classification, calculated what the average human judgement would be regarding the facial beauty portrayed in the image. Schmid, Marx and Samal [SMS08] proposed a regression-based approach to analyse the significance of symmetry, neoclassical canon and golden ratio in the attractiveness of a face. Their study focused on the geometry of the face by using a specific set of 29 landmarks. Their results suggest that whilst symmetry plays an important part in the perceived attractiveness, its role is secondary to those defined by the neoclassical canons and golden ratios. Van Loon et al. [vLMP+10] discuss the implementation of the 3dMD system to evaluate stereophotogrammetry as a method of documenting volumetric changes to the nose in patients with a cleft lip (CP) or cleft lip and palate (CLP) after secondary open rhinoplasty. The main goal of surgery was to acquire greater symmetry. It was found that the symmetry of the nose improved significantly and the 3D system was seen to be a suitable method for evaluating these volumetric changes.

Each of these studies suggests that symmetry and golden ratio have the potential to play a significant part in the subjective perception of facial attractiveness. It is this search for a perceptually ideal facial structure that has led to a correlation between symmetry, golden ratio and attractiveness, and subsequently the development of models such as Marquadt s Phi Mask [Mar02]. And whilst the idea that a universal standard to classify beauty has been discredited in some areas [Hol08], it does not diminish the potential of such models to function as indicative tools for the analysis of facial structure. The amalgamation of real-time video data and computer-generated visual feedback, such as the discussed indicative tools and overlay metrics, has the capacity to provide objective and quantifiable data. Whilst augmented reality has been discussed in other works [DWG+17,CLL15] as a potential diagnostic and rehabilitative tool, limited work has been done to apply it in this context.

3 The AR Tool

In this section, the design of the tool for assessing facial symmetry will be explained. The basic functionality of the tool is to provide the users with measurements to show how symmetric the face is. In particular, the measurements should be visualized in an intuitive way such that users understand the readings easily. Also, interactivity is one of the important aspects of the tool as the surgeon and patient can see the results immediately. Finally, the tool should be easy to use and the hardware should be portable with simple set up procedures such that it can be used in a clinical environment (e.g. consultation room).

As a result, we decided to develop the prototype of the tool as an Augmented Reality (AR) app to achieve all the aforementioned features. The AR App is developed on Android platform using Java in Android studio. Inspired by the FaceSpotter [deV17] project which tracks faces in real-time and overlays interacting graphics on facial landmarks, the Google Face API [Goo16] is being used. The Google Face API [Goo16] provides the mobile App developers with a wide range of face-related functionalities including face recognition and face tracking. By this, the positions of facial landmarks as well as the head orientations (in Euler angles) can be detected.

The Google Face API can track 12 facial landmarks on each face. However, we found that the tracking accuracy for the left and right ear landmarks are significantly lower than other landmarks in our experiments. As a result, only 10 facial landmarks are used in the app, including left and right eyes, left and right ear tips, left and right cheeks, left and right mouth, nose base and mouth bottom. An example is shown in Figure 1(a). Having detected the facial landmarks, we compare the facial symmetry by providing 4 different modes:

3.1 Basic Information

The prototype of the AR app provides a wide range of basic information interactively. Since the accuracy of facial landmark tracking depends on various factors (such as the lighting condition, camera motion, movement of the subject, head orientation, etc), the tracked landmark locations and labels are displayed for the user to evaluate whether the landmarks are tracked correctly. Then, the tracked landmark locations can be used for further analysis. In order to assist the users to find out whether the face is symmetric, we designed the follow measurements to be overlaid on the live video stream (illustrated in Figure 1(a)):

Eye distance to the midline: With the facial landmarks tracked using the Google Face API, the *nose base* and *mouth bottom* landmarks are used for defining the midline. The distance between each of the eyes and the midline can be computed to evaluate if the eye positions are symmetric.

Horizontal eye level deviation: The deviation (in degree) can be computed by acute angle between the line drawn between two eyes and a horizontal line:

$$\theta_{hor} = \arccos\left(\frac{\sqrt{(p_{l.eye,x} - p_{r.eye,x})^2}}{\sqrt{(p_{l.eye,x} - p_{r.eye,x})^2 + (p_{l.eye,y} - p_{r.eye,y})^2}}\right) \quad (1)$$

where $p_{l.eye,x}$ and $p_{l.eye,y}$ are the x and y coordinates of the left eye, and $p_{r.eye,x}$ and $p_{r.eye,y}$ are the x and y coordinates of the right eye.

Vertical midline deviation: The deviation (in degree) can be computed by acute angle between the midline computed from the tracked facial landmarks and a vertical line:

$$\theta_{ver} = \arccos\left(\frac{\sqrt{(p_{mouth.b,y} - p_{nose.b,y})^2}}{\sqrt{(p_{mouth.b,x} - p_{nose.b,x})^2 + (p_{mouth.b,y} - p_{nose.b,y})^2}}\right) \quad (2)$$

where $p_{mouth.b,x}$ and $p_{mouth.b,y}$ are the x and y coordinates of the *mouth bottom* landmark, and $p_{nose.b,x}$ and $p_{nose.b,y}$ are the x and y coordinates of the *nose base* landmark.

3.2 Visualizing the Rule of Fifth - Vertical

Having tracked the landmarks for the ears, the face can be divided into 5 equal-width segments vertically. The width of each segment should be close to the width of one of the eyes. In addition, the width of the nose base should be close to the distance between the inner corners of the eyes. An example of the overlaid information is shown in Figure 1(b).

3.3 Visualizing the Rule of Third - Horizontal

A face can be uniformly divided into 3 segments (i.e. head top to the eye, eye to nose base, and nose base to chin) horizontally using the rule of third. However, tracking the outline of the face on smartphones can be challenging due to illumination variations. On the other hand, having tracked the landmarks for the eyes (i.e. eye level) and the nose, the height of the middle segment (eye to nose base) can be computed. By this, the other two segments can be estimated and an example is illustrated in Figure 1(c). The bottom segment can be further divided and the distance between the nose base and the middle of the mouth should be 1/3 of the segment height.

3.4 Visualizing the Marquardt Phi Mask

Stephen R. Marquardt [Mar02] proposed Marquardt Phi Mask to describe facial proportion for ideal or beautiful faces. The mask is derived from mathematics, and mostly related to the *Golden Ratio*. An example of the mask overlaid to a male subject is illustrated in Figure 1(d). The mask can be used as guidelines for make-up or even plastic surgery such that the facial landmarks appear to be closer to the corresponding parts on the mask. Positive feedback is received from the literature [Bas06,Jef04,Kim07] on measuring facial attractiveness using the mask. Since then, common variations of the mask for different age groups, gender and ethnic group are available [Mar18].

The mask can be used as a guideline to show whether the face is symmetric and if the deviations of the tracked facial landmarks adhere to the template. In the AR app, the mask is overlaid over the live video stream. Having detected the facial landmarks from the live video stream, the distance between two eyes is calculated and the mask is scaled accordingly as the eye distance of the mask is known. Next, the location of the mask will be updated by using the middle point between two eyes as the reference point.

4 Conclusion and Future Work

In this paper, an AR tool for assisting the user to evaluate facial symmetry interactively is proposed. A prototype of the AR app was developed on the Android platform. Important facial landmarks can be tracked tracked in the live video stream and 4 different types of commonly used facial symmetric measurement are provided. In the future, we would like to conduct a user study to evaluate the effectiveness of the AR tool in practical use.

Motivated by a recent study [PHTA16] which suggested that the Microsoft Kinect depth sensor can be used in a wide range of healthcare imaging applications, we would like to introduce a face assessment tool that can analyze live video and 3D information. Using AR devices which are equipped with depth cameras, such as Microsoft Hololens, could be a future direction for improving the prototype by providing 3D facial information for further analysis.

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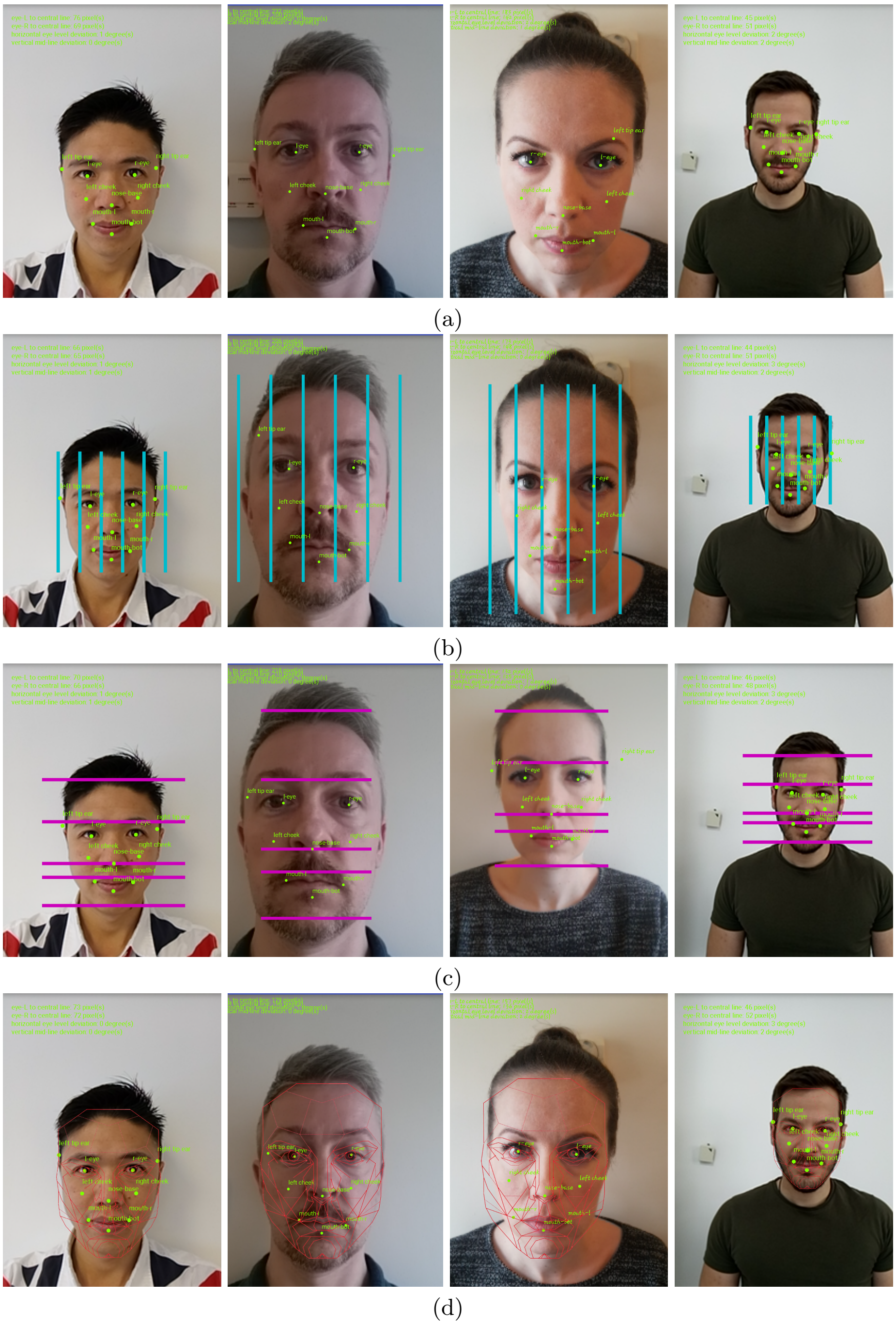

Fig. 1. The prototype AR app. Different types of information are overlaid on the live video stream. (a) Basic information. (b) The rule of fifth - uniformly dividing the face into 5 regions vertically. (c) The rule of third - uniformly dividing the face into 3 regions by horizontal lines. (d) Marquardt Phi Mask [Mar02].

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